IN THE U.S. PATENT AND TRADEMARK OFFICE

In re Patent Application of:
Daniele PRESSATO et al.

Application No.: 10/812,587   Confirmation No.: 2626

Filed: March 29, 2004   Art Unit: 1623

For: BIOMATERIALS FOR PREVENTING POST-   Examiner: L. C. Maier
SURGICAL ADHESIONS COMPRISED OF
HYALURONIC ACID DERIVATIVES

DECLARATION SUBMITTED UNDER 37 C.F.R. § 1.132

Honorable Commissioner
Of Patents and Trademarks
P.O. Box 1450
Alexandria, VA 22313-1450   October 18, 2007

Sir:

I, Dr Anna Maria Zanellato of Fidia farmaceutici SpA, Italy, do hereby declare the following:

I have attached a copy of my curriculum vitae to this Declaration.

I am working as Scientific Assistant to the Patent Deparment and I have worked in the field of cellular biology for 13 years.

I am familiar with the above referenced patent application, as well as the development, usages and properties of hyaluronic acid biomaterials.

I have read and understand the subject matter of the Office Action of June 18, 2007.

The following comments are offered in support of the patentability of the instant invention.

In the Office Action of June 18, 2007 the Examiner states "...Huang had taught that the efficacy of the product is a function of viscosity and degree of crosslinking." Unfortunately, the Examiner is wrong.

At column 4, lines 3-5 Huang teaches that the most preferred crosslinked gel to prevent the adhesions will be in the viscosity range of from 2,500 cps (i.e. 2.5 Pa*s) to 100,000 cps (i.e. 100 Pa*s). The instant application claims a gel with at least 200 Pa*s or, using Huang's units, 200,000 cps. On page 5, Example 1-b uses HA crosslinked gel with 88,600 cps of viscosity (i.e. 88.6 Pa*s) in the testing protocol. Examples 2 and 4 use gels with 60,200 cps (60.2 Pa*s). Example 5 teaches that "a clear trend towards improved efficacy with increasing crosslinking density [i.e. degree of crosslinking] was observed in ... Table 4" (column 11, lines 32-34). In fact, Table 4 shows that 20% adhesions are produced from a gel with 1% degree of crosslinking and 1570 cps (i.e. 1.57 Pa*s) of viscosity while a gel having a 5% degree of crosslinking and 2560 cps (2.56 Pa*s) viscosity gives 62% adhesions. Therefore, these data teach that the % of adhesions is independent of a gel's viscosity.

This aspect is clarified in Table 6 where it is evident how a gel with a 25% degree of crosslinking with a viscosity of 7660 cps (7.66 Pa*s) gives 49% adhesions while the gel with the same % of crosslinking but greater viscosity generates 91% adhesions. In addition, Table 6 shows that fewer adhesions (27%) are produced by a gel with 50%

crosslinking and 8840 cps (8.84 Pa*s) whereas the gel with the higher viscosity (146,000 cps or 146 Pa*s) gives only 49% adhesions.

This evidence is supported by Huang's conclusions where he affirms in column 11, lines 41+ that the efficacy of HA increases with the crosslinking density, i.e. the degree of crosslinking. Therefore, this reference teaches away from a product's efficacy of adhesion prevention being determined by viscosity: Huang actually teaches the contrary – that viscosity data are irrelevant to prevent tissue adhesions. Consequently, the Examiner's statement that the data disclosed in the Specification which shows that the ability of the instant product to prevent adhesions with increases with viscosity is not unexpected results but is "exactly consistent with what is known in the art and does not appear to be unexpected" in a wrong conclusion.

Similarly, the Examiner's statement that the art teaches how to prepare a product for optimal anti-adhesion properties (page 5 of the current Office Action, lines 6-7 is incorrect. As just discussed, Huang teaches that only the degree of crosslinking matters and Della Valle teaches only the preparation of a 5% HA crosslinked gel, i.e. there is no discussion viscosity. It is only in Study 8 presented in the instant application that the role of viscosity in adhesion prevention is determined.

Thus, the combination of the Della Valle reference, the Malson reference and the Huang reference, with or without any of the other cited references, do not teach the instant invention or suggest that viscosity is a critical feature of the invention.

It is only in Study 8 of the current application that the viscosity associated with a particular degree of crosslinking is shown to be important in preventing adhesions. Study 8 compares the efficacy of five (5) different batches (A-E) of 5% autocrosslinked

hyaluronic acid ("ACP") that differ only in the viscosity associated with each batch. As can be seen from Tables 4 and 5 (page 56 of the current application), not all 5% ACP gels produced the same results. Only those with a viscosity higher than 200 Pa^*sec^{-1} (see page 52) were effective in significantly reducing the numbers of adhesions. In fact, when the viscosity was below 200 Pa^*sec^{-1}, the percentage of adhesions were greater than untreated controls. This was an unexpected and surprising result. Our expectation was that viscosity would have no effect on the ability to prevent adhesions because that is what was taught in the prior art. Therefore, to find that viscosity was a critical factor in the ability of a crosslinked hyaluronic acid derivative to prevent adhesions was totally unexpected.

Fidia subsequently conducted additional experiments, again using gels all of which had the same degree of crosslinking (see Exhibit A). Our expectation was that since adhesion prevention increased as crosslinking increased, adhesion prevention would also increase as viscosity increased. Surprisingly, this was not the case. Instead we found that, at least in the case of spine surgery, viscosity of 900 Pa^*sec^{-1} failed to reduce the number of adhesions, although unlike very low viscosity values the number of adhesions did not increase.

In conclusion, the prior art taught nothing about the role of viscosity in the ability of crosslinked hyaluronic acid derivatives to prevent adhesions. It was only because of the experiments leading up to the claimed invention that the unexpected role of viscosity was determined. That is, the prior art provided no expectation that 4.5-5.0% crosslinked hyaluronic acid products having only particular viscosities would be advantageous for preventing surgical adhesions.

The undersigned hereby declares that all statements made herein based upon knowledge are true, and that all statements made based upon information and belief are believed to be true; and further, that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

DATED: 18 October 2007

Dr. Anna Maria Zanellato

CURRICULUM VITAE
Anna Zanellato

I, Anna Zanellato, being duly sworn, depose and say that:

- I am an Italian citizen residing at Bovolenta, Padua, Italy
- I am familiar with the English language.

I further declare that:

- I graduated in Biology at the University of Padua in the academic year 1987
- I am author of 19 scientific publications.

Previous job experience:

- From 1987 to 1990 I worked at the University Department of General Pathology as researcher, where I was involved in a study pertaining to smooth muscles cell cultures; moreover I studied the variations in myosin compositions that occur in situations of vascular pathologies such as Hypertension and Atherosclerosis.

- In the years 1990-2001, I worked at Fidia farmaceutici as senior researcher and my research activity involved: analysis of the action mechanism of various trophic factors of the central nervous system; studies utilising neuronal cultures to select new, pharmacologically active, chemical molecules to prevent different types of neuronal pathologies; other studies concerning the growth and proliferation of bovine, rabbit, human, mesenchymal/articular/fibroblastic cell cultures on biomaterials.

Current job:

- I am working as Scientific Assistant to the Fidia farmaceutici. Patent Department, Italy.

EXHIBIT 1

Effect pf ACP gel in preventing epidural adhesions after spine surgery

Materials and methods

Twenty-four adult rats were used in this study. The animals were anesthetized by an intraperitoneal injection of 6% pentobarbital solution (1.5ml/Kg). Under a surgical microscope, a laminectomy was performed from lumbar vertebra L5 toL6. The ligament flavum and epidural fat were removed, thus leaving a clean dura mater exposed for the full extent of laminectomy.

Once the laminectomy site was prepared and hemostasis obtained, the animals were divided into four groups.

In treatment **group I** (n=6) ACP gel (60mg/ml) with viscosity of <u>400</u> Pa.s (a shear rate 1 s^{-1}) was applied onto the exposed dura mater and also around the freed nerve roots. The deposited ACP gel filt the laminectomy defect.

In treatment **group II** (n=6) ACP gel (75mg/ml) with viscosity of <u>800</u> Pa.s (a shear rate 1 s^{-1}) was applied.

In treatment **group III** (n=6) ACP gel (80mg/ml) with viscosity of <u>950</u> Pa.s (a shear rate 1 s^{-1}) was applied.

In the control group (**group IV** (n=6)), no treatment was done (Untreated).

After the above procedures, the surgical wound was closed in layers with 4-0 nylon sutures without further irrigation.

The animals were carefully returned to their cages and then followed for four months.

Clinical observation

All animals were healthy and ambulatory without neurological deficits after surgery.

No superficial infection was found in any rats. The skin incision had healed within 1 week.

Gross anatomical observation

Four months after surgery and treatment, all rats were re-anesthetized and, under the surgical microscope, the initial surgical wound was re-opened.

The facility/difficulty of re-exposing the dura mater and the nerve roots were observed, and epidural adhesions were classified and described as 0° (no epidural adhesion), 1° (a little), 2° (moderate) and 3° (important).

The overall resuls are illustrated in <u>Table 1</u>.

In ACP gel treated groups I and II with viscosity of 400 and 800 Pa.s, due to the adhesion tissue containing much less fibrosis, the adhesions from the dura mater were easily removed without injuring it, and, compared with the untreated control, the dense and thickness of the epidural adhesion tissue were much less important.

In the ACP gel treated group III and in the untreated control group, the dura mater damage occurred while removing the adhesions, thus inducing a leakage of cerebro-spinal fluid.

Conclusion

ACP gels with viscosity data of 400 and 800 Pa.s are effective in the prevention/reduction of post surgical adhesions formation in a rat spine surgery model.

ACP gel with viscosity data of 900 Pa.s gave the highest adhesion grade like the untreated control group.

Table 1 : Degree of epidural adhesion after spine surgery
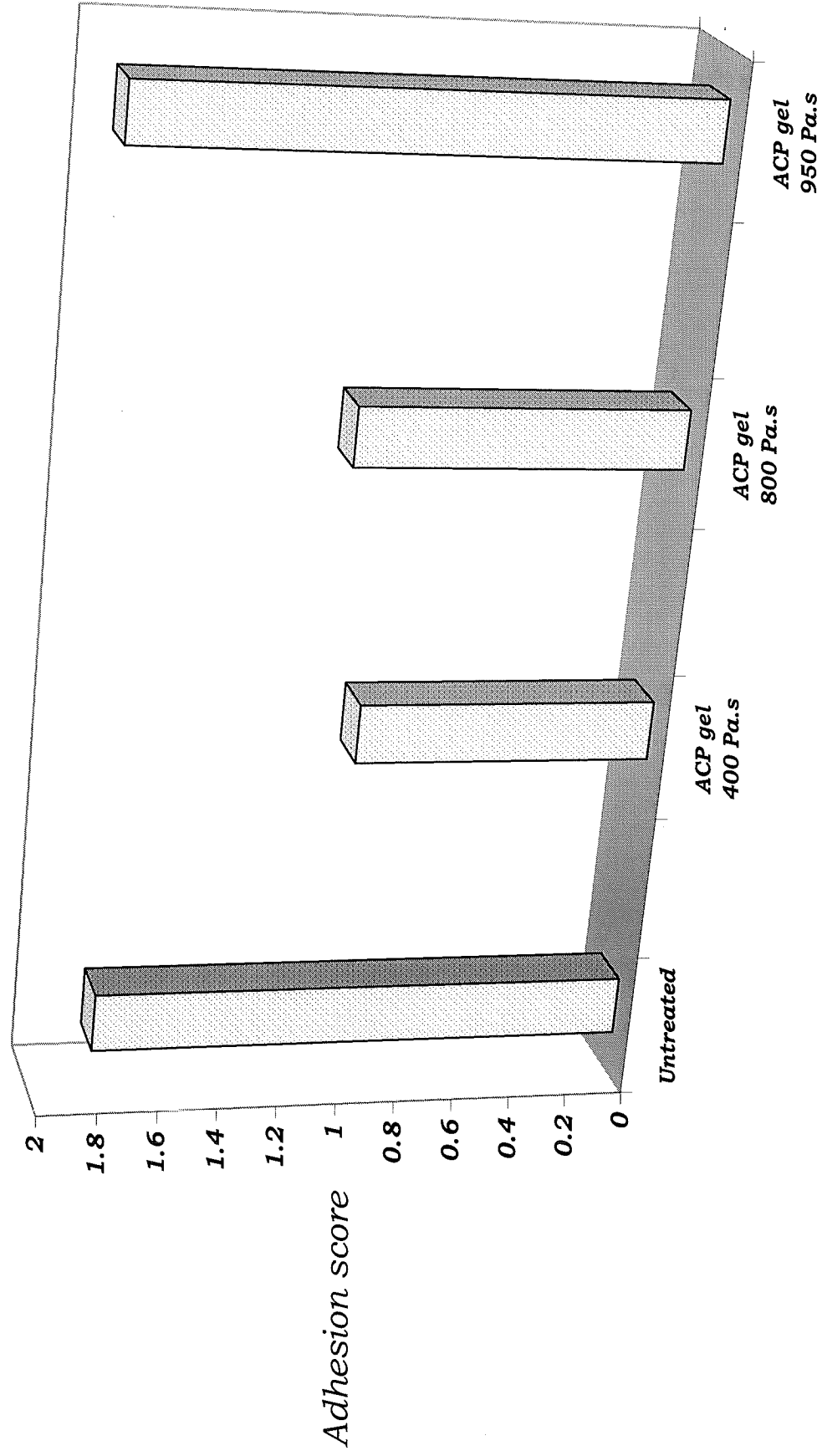
REFERENCE 1

For LDPE 2420 F, the Bagley plots have been fitted with both forms (4) and (5) as can be seen from Fig.3. Pronounced non-linear behavior exist as $a_i \gg 10$ as can be seen from table 3. For all shear rates the Bagley pressure determined with form (4) with $a_3 = p_a$, is twice as high as predicted from the linear form according (5).

It can be concluded that polynominal curve fitting of Bagley functions supported with a coefficient analyses on a routine basis is well suited to study non-linearities of Bagley functions in more details.

Conclusion

Wide speed coverage of modern capillary rheometers with servo-hydraulic drive systems in combination with user friendly software tools for appropriate modeling of the viscosity function significantly extend the application of these rheometers for broad shear rate rheology.

It is also shown that models from Sabia and Yasuda predict the Newtonian plateau based on capillary data alone.

Bagley corrections based on three or more experiments should use polynominal fit to make sure correct extrapolation of the Bagley pressure p_e.

Nomenclature :

η	viscosity [Pa*s]
η_0	zero-shear viscosity [Pa*s]
λ	characteristic time [s] (Yasuda model)
n,a	dimensionless parameter (Yasuda model)
λ_c	characteristic time [s] (Winter-Carreau model)
α	dimensionless parameter (Winter-Carr. model)
λ_s	parameter from Sabia model [s]
a,b	coefficients from linear Bagley form [Pa]
a_i	coefficients from non-linear Bagley form [Pa]
p_e	Bagley entrance pressure [Pa]
Δp	pressure drop [Pa]
γ	shear rate [sec^{-1}]

References :

1. Yasuda K., Armstrong R.C., Cohen R.E., Rheologica Acta 20, 163-178, 1981
2. Plumley T.A., SPE proceedings, ANTEC, 1994
3. Winter H.H., Polymer Eng. Science 20, 1980
4. Sabia R. , J. Appl. Polym 7, 347, 1963
5. "WinRHEO", software for Goettfert capillary rheometers
6. Goettfert, unpublished investigations, 1997

Key Words :

capillary rheometry - broad spectrum rheology - viscosity models - non-linear Bagley corrections

Spe/antec 1998 Proceedings By SPe, Bruce c. carlstedt, mary J. stanaszek (1998) Contributor Robin goldstein et al CRC Press

REFERENCE 2

Viscosity   *Your continued donations keep Wikipedia running!*

ATT. 1

From Wikipedia, the free encyclopedia

Viscosity is a measure of the resistance of a fluid to deform under shear stress. It is commonly perceived as "thickness", or resistance to flow. Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction. Thus, water is "thin", having a lower viscosity, while vegetable oil is "thick" having a higher viscosity. All real fluids (except superfluids) have some resistance to shear stress, but a fluid which has no resistance to shear stress is known as an **ideal fluid** or **inviscid fluid**.[1]

When looking at a value for viscosity, the number that one most often sees is the coefficient of viscosity. Simply put, this quantity is the ratio between the pressure exerted on the surface of a fluid, in the lateral or horizontal direction, to the change in velocity of the fluid as you move down in the fluid (this is what is referred to as a velocity gradient). For example, at "room temperature", water has a nominal viscosity of 1.0×10^{-3} Pa·s and motor oil has a nominal apparent viscosity of 250×10^{-3} Pa·s.[2]

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Continuum mechanics

Key topics

Conservation of mass
Conservation of momentum
Navier-Stokes equations
Classical mechanics
Stress · Strain · Tensor
Solid mechanics
Solids · Elasticity

Plasticity · Hooke's law
Rheology · Viscoelasticity
Fluid mechanics
Fluids · Fluid statics
Fluid dynamics · Viscosity ·
Newtonian fluids
Non-Newtonian fluids
Surface tension
Scientists

Newton · Stokes · *others*

Etymology

The word "viscosity" derives from the Latin word "viscum" for mistletoe. A viscous glue was made from mistletoe berries and used for lime-twigs to catch birds.[3]

Newton's theory

In general, in any flow, layers move at different velocities and the fluid's viscosity arises from the shear stress between the layers that ultimately opposes any applied force.

Isaac Newton postulated that, for straight, parallel and uniform flow, the shear stress, τ, between layers is proportional

to the velocity gradient, $\partial u/\partial y$, in the direction perpendicular to the layers.

$$\tau = \eta \frac{\partial u}{\partial y}.$$

Here, the constant η is known as the *coefficient of viscosity*, the *viscosity*, the *dynamic viscosity*, or the *Newtonian viscosity*. Many fluids, such as water and most gases, satisfy Newton's criterion and are known as Newtonian fluids. Non-Newtonian fluids exhibit a more complicated relationship between shear stress and velocity gradient than simple linearity.

The relationship between the shear stress and the velocity gradient can also be obtained by considering two plates closely spaced apart at a distance y, and separated by a homogeneous substance. Assuming that the plates are very large, with a large area A, such that edge effects may be ignored, and that the lower plate is fixed, let a force F be applied to the upper plate. If this force causes the substance between the plates to undergo shear flow (as opposed to just shearing elastically until the shear stress in the substance balances the applied force), the substance is called a fluid. The applied force is proportional to the area and velocity of the plate and inversely proportional to the distance between the plates. Combining these three relations results in the equation $F = \eta(Au/y)$, where η is the proportionality factor called the *absolute viscosity* (with units Pa·s = kg/(m·s) or slugs/(ft·s)). The absolute viscosity is also known as the *dynamic viscosity*, and is often shortened to simply *viscosity*. The equation can be expressed in terms of shear stress; $\tau = F/A = \eta(u/y)$. The rate of shear deformation is u/y and can be also written as a shear velocity, du/dy. Hence, through this method, the relation between the shear stress and the velocity gradient can be obtained.

James Clerk Maxwell called viscosity *fugitive elasticity* because of the analogy that elastic deformation opposes shear stress in solids, while in viscous fluids, shear stress is opposed by *rate* of deformation.

Laminar shear of fluid between two plates. Friction between the fluid and the moving boundaries causes the fluid to shear. The force required for this action is a measure of the fluid's viscosity. This type of flow is known as a Couette flow.
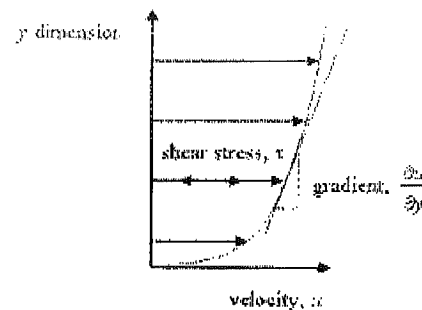
Laminar shear, the non-linear gradient, is a result of the geometry the fluid is flowing through (e.g. a pipe).

Viscosity Measurement

Viscosity is measured with various types of viscometer. Close temperature control of the fluid is essential to accurate measurements, particularly in materials like lubricants, whose viscosity (-40 < sample temperature <0) can double with a change of only 5 deg. C.

For some fluids, it is a constant over a wide range of shear rates. The fluids without a constant viscosity are called Non-Newtonian fluids.
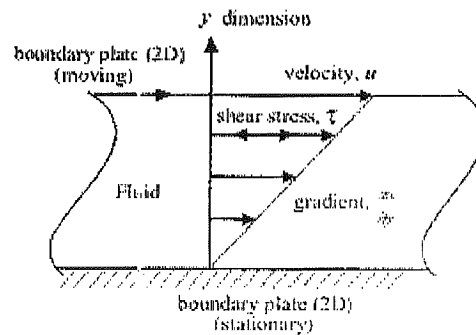
One of the most common methods of measuring kinematic viscosity is using the glass capillary viscometer.

In paint industries, viscosity is commonly measured with a Zahn cup, in which the efflux time is determined and given to customers. The efflux time can also be converted to kinematic viscosities (cSt) through the conversion equations.

Also used in paint, a Stormer viscometer uses load-based rotation in order to determine viscosity. It uses units, Krebs units (KU), unique to this viscometer.

Vibrating viscometers can also be used to measure viscosity. These models use vibration rather than rotation to measure viscosity.

Units of Measure

Viscosity (dynamic/absolute viscosity)

The IUPAC symbol for viscosity is the Greek symbol eta (η), and dynamic viscos ty is also commonly referred to using the Greek symbol mu (μ). The SI physical unit of dynamic viscosity is the pascal-second (Pa·s), which is identical to 1 kg·m^{-1}·s^{-1}. If a fluid with a viscosity of one Pa·s is placed between two plates, and one plate is pushed sideways with a shear stress of one pascal, it moves a distance equal to the thickness of the layer between the plates in one second.

The name poiseuille (Pl) was proposed for this unit (after Jean Louis Marie Poiseuille who formulated Poiseuille's law of viscous flow), but not accepted internationally. Care must be taken in not confusing the poiseuille with the poise named after the same person.

The cgs physical unit for dynamic viscosity is the *poise*[4] (P: IPA: [pwaz])) named after Jean Louis Marie Poiseuille. It is more commonly expressed, particularly in ASTM standards, as *centipoise* (cP). The centipoise is commonly used because water has a viscosity of 1.0020 cP (at 20 °C; the closeness to one is a convenient coincidence).

$$1\ P = 1\ g\cdot cm^{-1}\cdot s^{-1}$$

The relation between Poise and Pascal-second is:

$$10\ P = 1\ kg\cdot m^{-1}\cdot s^{-1} = 1\ Pa\cdot s$$
$$1\ cP = 0.001\ Pa\cdot s = 1\ mPa\cdot s$$

Kinematic viscosity: ν

In many situations, we are concerned with the ratio of the viscous force to the inertial force, the latter characterised by the fluid density ρ. This ratio is characterised by the *kinematic viscosity* (ν), defined as follows:

$$\nu = \frac{\eta}{\rho}.$$

where η is the (dynamic) viscosity, and ρ is the density.

Kinematic viscosity (Greek symbol: ν) has SI units (m^2·s^{-1}). The cgs physical unit for kinematic viscosity is the *stokes* (abbreviated S or St), named after George Gabriel Stokes. It is sometimes expressed in terms of *centistokes* (cS or cSt). In U.S. usage, *stoke* is sometimes used as the singular form.

$$1\ stokes = 100\ centistokes = 1\ cm^2\cdot s^{-1} = 0.0001\ m^2\cdot s^{-1}.$$
$$1\ centistokes = 1\ mm^2/s$$

Dynamic versus kinematic viscosity

Conversion between kinematic and dynamic viscosity, is given by $\nu\rho = \eta$. Note that the parameters must be given in SI units not in P, cP or St.

For example, if $\nu = 1$ St (=0.0001 m^2·s^{-1}) and $\rho = 1000$ kg m^{-3} then $\eta = \nu\rho = 0.1$ kg m^{-1}·s^{-1} = 0.1 Pa·s.

A plot of the kinematic viscosity of air as a function of absolute temperature is available on the Internet.[5]

Molecular origins

The viscosity of a system is determined by how molecules constituting the system interact. There are no simple but correct expressions for the viscosity of a fluid. The simplest exact expressions are the Green-Kubo relations for the linear shear viscosity or the Transient Time Correlation Function expressions derived by Evans and Morriss in 1985. Although these expressions are each exact in order to calculate the viscosity of a dense fluid, using these relations requires the use of molecular dynamics computer simulation.

Gases

Viscosity in gases arises principally from the molecular diffusion that transports momentum between layers of flow. The kinetic theory of gases allows accurate prediction of the behaviour of gaseous viscosity, in particular that, within the regime where the theory is applicable:

- Viscosity is independent of pressure(except in the high pressure and very low pressure under atmospheric pressure); and
- Viscosity increases as temperature increases.

Effect of temperature on the viscosity of a gas

The Sutherland's formula can be used to derive the dynamic viscosity of an ideal gas as a function of the temperature:

$$\eta = \eta_0 \frac{T_0 + C}{T + C} \left(\frac{T}{T_0}\right)^{3/2}$$

where:

- η = viscosity in (Pa·s) at input temperature T
- η_0 = reference viscosity in (Pa·s) at reference temperature T_0
- T = input temperature in kelvin
- T_0 = reference temperature in kelvin
- C = Sutherland's constant for the gasous material in question

Valid for temperatures between $0 < T < 555$ K with an error due to pressure less than 10% below 3.45 MPa

Sutherland's constant and reference temperature for some gases

Gas	C [K]	T_0 [K]	η_0 [10^{-6} Pa s]
air	120	291.15	18.27
nitrogen	111	300.55	17.81
oxygen	127	292.25	20.18
carbon dioxide	240	293.15	14.8
carbon monoxide	118	288.15	17.2
hydrogen	72	293.85	8.76
ammonia	370	293.15	9.82
sulphur dioxide	416	293.65	12.54

Viscosity of a dilute gas

The Chapman-Enskog equation[6] may be used to estimate viscosity for a dilute gas. This equation is based on semi-theorethical assumption by Chapman and Enskoq. The equation requires three empirically determined parameters: the collision diameter (σ), the maximum energy of attraction divided by the Boltzman constant (ϵ/κ) and the collision integral ($\omega(T^*)$).

$$\eta_0 x 10^7 = 266.93 \frac{(MT)^{1/2}}{\sigma^2 \omega(T^*)} \; ; T^* = \kappa T/\epsilon$$

- η_0 = viscosity for dilute gas (uP)
- M = molecular weight (kg/m^3)
- T = temperature (K)
- σ = the collision diameter (Å)
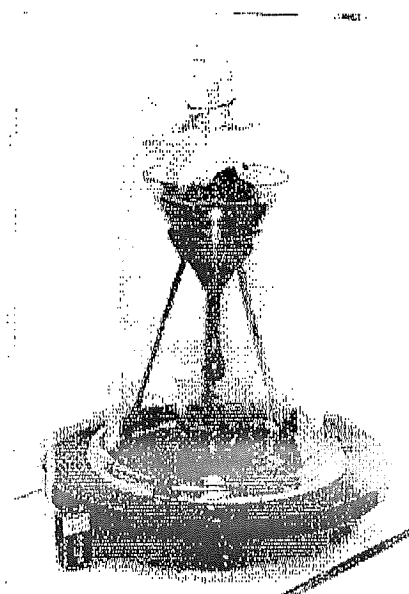
P tch has a viscosity approximately 100 billion times that of water.

- ε / κ = the maximum energy of attraction divided by the Boltzman constant · K)
- ω_η = the collision integral
- T^* = reduced temperature (K)

Liquids

In liquids, the additional forces between molecules become important. This leads to an additional contribution to the shear stress though the exact mechanics of this are still controversial. Thus, in liquids:

- Viscosity is independent of pressure (except at very high pressure); and
- Viscosity tends to fall as temperature increases (for example, water viscosity goes from 1.79 cP to 0.28 cP in the temperature range from 0 °C to 100 °C); see temperature dependence of liquid viscosity for more details.

The dynamic viscosities of liquids are typically several orders of magnitude higher than dynamic viscosities of gases.

Viscosity blending of liquids

The viscosity blending of two or more liquids having different viscosities is a three-step procedure. The first step is to calculate the Viscosity Blending Index (VBI) of each component of the blend using the following equation (known as a Refutas equation): [7][8]

(1) $\text{VBN} = 14.534 \times \ln[\ln(v + 0.8)] + 10.975$

where v is the viscosity in centistokes (cSt) and **ln** is the natural logarithm (Log_e). It is important that the viscosity of each component of the blend be obtained at the same temperature.

The next step is to calculate the VBN of the blend, using this equation:

(2) $\text{VBN}_{\text{Blend}} = [w_A \times \text{VBN}_A] + [w_B \times \text{VBN}_B] + \dots + [w_X \times \text{VBN}_X]$

where w is the weight fraction (i.e., % ÷ 100) of each component of the blend.

Once the viscosity blending number of a blend has been calculated using equation (2), the final step is to determine the viscosity of the blend by using the invert of equation (1):

(3) $v = e^{e^{(\text{VBN} - 10.975) \div 14.534}} - 0.8$

where **VBN** is the viscosity blending number of the blend and e is the transcendental number 2.71828, also known as Euler's number.

Viscosity of materials

The viscosity of air and water are by far the two most important materials for aviation aerodynamics and shipping fluid dynamics. Temperature plays the main role in determining viscosity.

Viscosity of air

The viscosity of air depends mostly on the temperature. At 15.0 °C, the viscosity of air is 1.78×10^{-5} kg/(m·s). You can get the viscosity of air as a function of altitude from the eXtreme High Altitude Calculator

Viscosity of water

The viscosity of water is 8.90×10^{-4} Pa·s or 8.90×10^{-3} dyn·s/cm² at about 25 °C.
As a function of temperature T (K): $\mu(\text{Pa·s}) = A \times 10^{B/(T-C)}$
where $A = 2.414 \times 10^{-5}$ Pa·s ; $B = 247.8$ K ; and $C = 140$ K.

Viscosity of various materials

Some dynamic viscosities of Newtonian fluids are listed below:

Gases (at 0 °C):

	viscosity [Pa·s]
hydrogen	8.4×10^{-6}
air	17.4×10^{-6}
xenon	21.2×10^{-6}

Liquids (at 25 °C):

	viscosity [Pa·s]	viscosity [cP]
liquid nitrogen @ 77K	0.158×10^{-3}	0.158
acetone*	0.306×10^{-3}	0.306
methanol*	0.544×10^{-3}	0.544
benzene*	0.604×10^{-3}	0.604
ethanol*	1.074×10^{-3}	1.074
water	0.894×10^{-3}	0.894
mercury*	1.526×10^{-3}	1.526
nitrobenzene*	1.863×10^{-3}	1.863
propanol*	1.945×10^{-3}	1.945
sulfuric acid*	24.2×10^{-3}	24.2
olive oil	.081	81
glycerol*	.934	934
castor oil	985×10^{-3}	985
HFO-380	2.022	2022
pitch	2.3×10^{8}	2.3×10^{11}

Example of the viscosity of milk and water. Liquids with higher viscosities will not make such a splash when poured at the same velocity.

* Data from CRC Handbook of Chemistry and Physics, 73rd edition, 1992-1993.

Fluids with variable compositions, such as honey, can have a wide range of viscosities.

A more complete table can be found here, including the following:

	viscosity [cP]
honey	2,000–10,000
molasses	5,000–10,000
molten glass	10,000–1,000,000
chocolate syrup	10,000–25,000
chocolate*	45,000–130,000 [1]
ketchup*	50,000–100,000
peanut butter	~250,000
shortening*	~250,000

* These materials are highly non-Newtonian.

Viscosity of solids

On the basis that all solids flow to a small extent in response to shear stress some researchers[9][10] have contended that substances known as amorphous solids, such as glass and many polymers, may be considered to have viscosity. This has led some to the view that solids are simply liquids with a very high viscosity, typically greater than 10^{12} Pa·s. This position is often adopted by supporters of the widely held misconception that glass flow can be observed in old buildings. This distortion is more likely the result of glass making process rather than the viscosity of glass.[11]

However, others argue that solids are, in general, elastic for small stresses while fluids are not.[12] Even if solids flow at higher stresses, they are characterized by their low-stress behavior. Viscosity may be an appropriate characteristic for solids in a plastic regime. The situation becomes somewhat confused as the term *viscosity* is sometimes used for solid materials, for example Maxwell materials, to describe the relationship between stress and the rate of change of strain, rather than rate of shear.

These distinctions may be largely resolved by considering the constitutive equations of the material in question, which take into account both its viscous and elastic behaviors. Materials for which both their viscosity and their elasticity are important in a particular range of deformation and deformation rate are called *viscoelastic*. In geology, earth materials that exhibit viscous deformation at least three times greater than their elastic deformation are sometimes called rheids.

Bulk viscosity

The negative-one-third of the trace of the stress tensor is often identified with the thermodynamic pressure,

$$-\frac{1}{3}T_a^a = p,$$

which only depends upon the equilibrium state potentials like temperature and density (equation of state). In general, the trace of the stress tensor is the sum of thermodynamic pressure contribution plus another contribution which is proportional to the divergence of the velocity field. This constant of proportionality is called the **bulk viscosity**.

Eddy viscosity

In the study of turbulence in fluids, a common practical strategy for calculation is to ignore the small-scale *vortices* (or *eddies*) in the motion and to calculate a large-scale motion with an *eddy viscosity* that characterizes the transport and dissipation of energy in the smaller-scale flow (see *large eddy simulation*). Values of eddy viscosity used in modeling ocean circulation may be from 5×10^4 to 10^6 Pa·s depending upon the resolution of the numerical grid.

Fluidity

The reciprocal of viscosity is *fluidity*, usually symbolized by $\varphi = 1/\eta$ or $F = 1/\eta$, depending on the convention used, measured in *reciprocal poise* (cm·s·g^{-1}), sometimes called the *rhe*. *Fluidity* is seldom used in engineering practice.

The concept of fluidity can be used to determine the viscosity of an ideal solution. For two components a and b, the fluidity when a and b are mixed is

$$F \approx \chi_a F_a + \chi_b F_b$$

which is only slightly simpler than the equivalent equation in terms of viscosity:

$$\eta \approx \frac{1}{\chi_a/\eta_a + \chi_b/\eta_b}$$

where χ_a and χ_b is the mole fraction of component a and b respectively, and η_a and η_b are the components pure viscosities.

The linear viscous stress tensor

(See *Hooke's law* and *strain tensor* for an analogous development for linearly elas ic materials.)

Viscous forces in a fluid are a function of the rate at which the fluid velocity is chs.nging over distance. The velocity at any point $\mathbf{r}$ is specified by the velocity field $\mathbf{v}(\mathbf{r})$. The velocity at a small distance dr from point $\mathbf{r}$ may be written as a Taylor series:

$$\mathbf{v}(\mathbf{r} + dr) = \mathbf{v}(\mathbf{r}) + \frac{d\mathbf{v}}{dr}dr + \dots$$

where $\dfrac{d\mathbf{v}}{dr}$ is shorthand for the dyadic product of the del operator and the velocity:

$$\frac{d\mathbf{v}}{dr} = \begin{bmatrix} \frac{\partial v_x}{\partial x} & \frac{\partial v_x}{\partial y} & \frac{\partial v_x}{\partial z} \\ \frac{\partial v_y}{\partial x} & \frac{\partial v_y}{\partial y} & \frac{\partial v_y}{\partial z} \\ \frac{\partial v_z}{\partial x} & \frac{\partial v_z}{\partial y} & \frac{\partial v_z}{\partial z} \end{bmatrix}$$

This is just the Jacobian of the velocity field. Viscous forces are the result of relati ve motion between elements of the fluid, and so are expressible as a function of the velocity field. In other words, the orces at $\mathbf{r}$ are a function of $\mathbf{v}(\mathbf{r})$ and all derivatives of $\mathbf{v}(\mathbf{r})$ at that point. In the case of linear viscosity, the viscous force will be a function of the Jacobian tensor alone. For almost all practical situations, the linear approximation s sufficient.

If we represent x, y, and z by indices 1, 2, and 3 respectively, the i,j component of the Jacobian may be written as $\partial_i v_j$ where ∂_i is shorthand for $\partial/\partial x_i$. Note that when the first and higher derivative terms are zero, the velocity of all fluid elements is parallel, and there are no viscous forces.

Any matrix may be written as the sum of an antisymmetric matrix and a symmetric matrix, and this decomposition is independent of coordinate system, and so has physical significance. The velocity field may be approximated as:

$$v_i(\mathbf{r} + dr) = v_i(\mathbf{r}) + \frac{1}{2}\left(\partial_i v_j - \partial_j v_i\right)dr_i + \frac{1}{2}\left(\partial_i v_j + \partial_j v_i\right)dr$$

where Einstein notation is now being used in which repeated indices in a product ar c implicitly summed. The second term on the left is the asymmetric part of the first derivative term, and it represents a rigid rotation of the fluid about $\mathbf{r}$ with angular velocity ω where:

$$\omega = \nabla \times \mathbf{v} = \frac{1}{2}\begin{bmatrix} \partial_2 v_3 - \partial_3 v_2 \\ \partial_3 v_1 - \partial_1 v_3 \\ \partial_1 v_2 - \partial_2 v_1 \end{bmatrix}$$

For such a rigid rotation, there is no change in the relative positions of the fluid elements, and so there is no viscous force associated with this term. The remaining symmetric term is responsible for the viscous forces in the fluid. Assuming the fluid is isotropic (i.e. its properties are the same in all directions), then the most general way that the symmetric term (the rate-of-strain tensor) can be broken down in a coordinate-inde endent (and therefore physically real) way is as the sum of a constant tensor (the rate-of-expansion tensor) and a trac eless symmetric tensor (the rate-of-shear tensor):

$$\frac{1}{2}\left(\partial_i v_j + \partial_j v_i\right) = \frac{1}{3}\partial_k v_k \delta_{ij} + \left(\frac{1}{2}\left(\partial_i v_j + \partial_j v_i\right) - \frac{1}{3}\partial_k v_k \delta_{ij}\right)$$

where δ_{ij} is the unit tensor. The most general linear relationship between the stress ensor σ and the rate-of-strain tensor is then a linear combination of these two tensors:[13]

$$\sigma_{visc:ij} = \zeta \partial_k v_k \delta_{ij} + \eta\left(\partial_i v_j + \partial_j v_i - \frac{2}{3}\partial_k v_k \delta_{ij}\right)$$

where ζ is the coefficient of bulk viscosity (or "second viscosity") and η is the coefficient of (shear) viscosity.

The forces in the fluid are due to the velocities of the individual molecules. The velocity of a molecule may be thought of as the sum of the fluid velocity and the thermal velocity. The viscous stress tensor described above gives the force due to the fluid velocity only. The force on an area element in the fluid due to the thermal velocities of the molecules is just the hydrostatic pressure. This pressure term ($p\delta_{ij}$) must be added to the viscous stress tensor to obtain the total stress tensor for the fluid.

$$\sigma_{ij} = p\delta_{ij} + \sigma_{visc\,ij}$$

The infinitesimal force dF_i on an infinitesimal area dA_i is then given by the usual relationship:

$$dF_i = \sigma_{ij}dA_j$$

See also

- Deborah number
- Dilatant
- Hyperviscosity syndrome
- Rheology
- Thixotropy
- Viscometer
- Viscometry
- Viscosity index

References

1. ^ Symon, Keith (1971). *Mechanics*, Third Edition, Addison-Wesley. ISBN 0-201-07392-7.
2. ^ Raymond A. Serway (1996). *Physics for Scientists & Engineers*, 4th Edition, Saunders College Publishing. ISBN 0-03-005932-1.
3. ^ The Online Etymology Dictionary
4. ^ IUPAC definition of the Poise
5. ^ James Ierardi's Fire Protection Engineering Site
6. ^ J.O. Hirshfelder, C.F. Curtis and R.B. Bird (1964). *Molecular theory of gases and liquids*, First Edition, Wiley. ISBN 0-471-40065-3.
7. ^ Robert E. Maples (2000). *Petroleum Refinery Process Economics*, 2nd Edition, Pennwell Books. ISBN 0-87814-779-9.
8. ^ C.T. Baird (1989), *Guide to Petroleum Product Blending*, HPI Consultants, Inc. HPI website
9. ^ The Physics Hypertextbook, by Glen Elert, retrieved on August 1, 2007.
10. ^ The Properties of Glass , page 6, retrieved on August 1, 2007
11. ^ "Antique windowpanes and the flow of supercooled liquids", by Robert C. Plumb, (Worcester Polytech. Inst., Worcester, MA, 01609, USA), J. Chem. Educ. (1989), 66 (12), 994-6
12. ^ Gibbs, Philip. Is Glass a Liquid or a Solid?. Retrieved on 2007-07-31.
13. ^ L.D. Landau and E.M. Lifshitz (translated from Russian by J.B. Sykes and W.H. Reid) (1997). *Fluid Mechanics*, 2nd Edition, Butterworth Heinemann. ISBN 0-7506-2767-0.

Additional reading

- Massey, B. S. (1983). *Mechanics of Fluids*, Fifth Edition, Van Nostrand Reinhold (UK). ISBN 0-442-30552-4.

External links

- Gas Dynamics Toolbox Calculate coefficient of viscosity for mixtures of gases using VHS model
- Physical Characteristics of Water A table of water viscosity as a function of temperature
- Glass Viscosity Measurement Viscosity measurement, viscosity units and fixpoints, glass viscosity calculation
- diracdelta.co.uk conversion between kinematic and dynamic viscosity.
- Industrial viscosity measurement by vibrating viscometer

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Lab 5: Fluid Dynamics Lab A

REFERENCE 3

ATT. 2

Questa è la versione .html del file contenuto in http://feh.osu.edu/Lectures/193sp05a/ENG%20H193A%20T ransport%20Phenomena%20-%20Fluid%20Flow%
20%20Rheology%20Lab%20Procedure.doc.
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Transport Phenomena, Fluid Flow, Rheology

Lab Procedure

Lab Objectives:

The objectives of the lab are:

- Introduce transport phenomena – fluid, energy and mass flow
- Introduce rheology (the study of the deformation and flow of fluids) and fluids classification
- Relate **viscosity** to flow behavior by measuring the **viscosity** and flow rates of Newtonian fluids using simple methods
- Measurement of **viscosity** using capillary viscometer
- Determine the relationship of fluid density to fluid **viscosity**.

Background Information:

Introduction to Transport Phenomena

The movement and use of energy in various forms is of concern to all engineering disciplines at some level. It is the basis of an area of study known as

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thermodynamics in which one learns that in any process (except those involving nuclear fission) energy is neither created nor destroyed. However, keeping track of the various forms of energy in a process is a complicated task and we will just touch on some simple principles in this laboratory exercise.

Most of us don't think twice about plugging an instrument or device into an outlet and making use of the electricity provided. In doing so, **we are taking advantage of electrical energy and converting it to mechanical energy** (turning a shaft on a motor), chemical energy (shooting electrons at a phosphor screen on a monitor), **and thermal energy (heat).** Our practical experience tells us that the latter form (heat) is *always* present no matter what. In fact, it is often a large part of the design process to reduce the amount of energy lost as heat because the heat can in some cases prove fatal to the device (for example in large integrated circuits). Roughly speaking, we define the efficiency of a process or device as the percent of the energy consumed by that device that is converted to uses *other* than heat (unless that is the purpose of the device). Devices that are designed to convert one form of energy directly into heat (gas furnaces for example) are typically some of the most efficient possible.

Chemical, civil, and mechanical engineers (and all others to some extent) are interested in the movement of energy, mass and **momentum** from place to place. The collective study of these movement processes is called "transport phenomena". This term simply conveys the fact that many transport processes in science and engineering are caused by forces that can be described by the same general equations. For example, the same mathematical equations that describe how heat transfers away from an integrated circuit chip can be used to describe how temperature changes in a chemical reactor. Savvy engineers are able to recognize these similarities and study them as the related fields they truly are. One of the basic principles in all transport phenomena calculations, including heat transfer, is that the rate of transport is directly related to the measured driving force. For example, in transport of momentum (fluid flow), pressure is the driving force and a difference in pressure between two points causes fluid to flow. Similarly in transport of energy (heat transfer) the rate of movement of heat energy from a hot body to a cold body is related to the difference in temperatures between the bodies. The exact formulation of these equations is very complex and beyond our scope here, however it is useful to recognize the relationship

In the Transport Phenomena lab we will deal with transport of momentum. Before examining fluid flow, rheology and classification of fluids will be introduced.

Introduction to Rheology and classification of fluids

Rheology is defined as the science of deformation and flow of matter. It describes the material properties of fluids (including gases) and semi-solid materials. Rheology is interdisciplinary and is used to describe interrelation between applied force (or stress), deformation, and time for a wide variety of materials such as oils, food, inks, polymers, clays, concrete etc. The common factor is that these materials exhibit some type of inelastic deformation or "flow" under stress and, therefore, cannot be treated as solids.

Fluid rheology is used to describe the consistency of different products, normally by the two components **viscosity** and **elasticity**. Viscosity describes resistance of the fluid to flow or its thickness. For example, the **viscosity** of molasses is higher than the **viscosity** of water. It can be measured in several ways. Elasticity describes the fluid's "memory" and results in a delay of the fluid's reaction to stress.

Lab 5: Fluid Dynamics Lab A

Based on flow behavior, fluids are normally divided into different groups.

- **Newtonian fluids** – whose **viscosity** is dependent only on temperature

Examples: Water, milk, sugar solution, mineral oil

- **Non-Newtonian fluids (time independent)** – whose **viscosity** is dependent not only on temperature but also on shear rate. Depending on how **viscosity** changes with shear rate, the flow behavior is characterized as:
   - Shear thinning, whose **viscosity** decreases with increased shear **rate**

Examples: Paint, shampoo, fruit juice concentrates, molten plastic

   - Shear thickening, whose **viscosity** increases with increased shear **rate**

Examples: wet sand and concentrated starch suspensions

   - Plastic, which exhibits a so-called yield value, *i.e.* a certain shear stress must be applied before flow occurs

Examples: toothpaste, hand cream, grease

- **Non-Newtonian fluids (time dependent)** – whose **viscosity** is dependent on temperature, shear rate and time. Depending on how **viscosity** changes with time the flow behavior is characterized as:
   - Time thinning – **viscosity** decreases with time

Examples: yogurt, paint

   - Time thickening – **viscosity** increases with time

Example: gypsum paste

In this lab, we will deal only with simple and commonly available Newtonian fluids. We will measure **viscosity** of such fluids using inexpensive (and approximate) methods.

Fluid flow

Fluid flow deals with transport of momentum. A flow occurs when there is a difference in pressure between two areas, and the flow is from a higher pressure point to

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Lab 5: Fluid Dynamics Lab A

a lower pressure area. Fluid flow is typically described as being laminar (streamlined with layers of similarly moving molecules) or turbulent (chaotic movement). See Figure 1. The equations that will be used in this lab assume laminar flow, although a means of confirming whether flow is laminar or turbulent is provided using Reynold's number.

Flow Direction

Flow Direction

LAMINAR FLOW (MOLECULAR)

If pressure drop is small

- flow will be relatively small and laminar
- fluid motion is smooth (ordered fashion) and transfer of momentum is molecular

TURBULENT FLOW (EDDY)

If pressure drop is large

- flow will be relatively large
- fluid motion is chaotic and transfer is with blocks of molecules (called eddies) moving in all directions

Figure 1: A comparison of laminar and turbulent flow in fluids.

The concepts discussed in this lab encompass many disciplines, including chemical engineering, mechanical engineering, industrial engineering, civil engineering, environmental engineering, food engineering, and bio-medical engineering, to name a few.

Equipment:

Lab 5: Fluid Dynamics Lab A

For this lab, there will be stations with different fluids to test for flow rates.

Each station will be supplied with the following materials and equipment for this lab:

- One stopwatch
- A plungerless graduated syringe with transparent Tygon tubing attached, mounted to vertical dowels on stands at separate tables (to eliminate fluid contamination).
- A Tygon tubing clamp.
- A Nalgene wash bottle for transferring fluids to the plungerless, mounted syringe, and catching fluid draining from the capillary tube apparatus. Fluid containers/reservoirs contain one of the following fluids:
  - o Canola Oil
  - o SAE 30 Motor Oil
  - o Castor Oil

NOTE: In this lab, all units should be in meters (m), kilograms (kg), seconds (s), kilograms per meter-second² (kg/m-s²) for pressure, and kilograms per meter-second (kg/m-s) for viscosity. For your information, $1'' = 2.54$ cm. 1 cm³ $= 1$mL. Pressure: 1 Pa $= 1$ N/m² $= 1$ (kg/m²)(m/s²) $= 1$ (kg/m-s²). Viscosity: 1 Pa-s $= 1$ N-s/m² $= 1$ (kg-s/m²)(m/s²) $= 1$ (kg/m-s).

Newtonian Fluid Properties and Relationships:

Fluid Flow Rate Through a Capillary

Reynold's number (dimensionless, must be <<2000 to indicate laminar fluid flow in a pipe or tube, for the remaining relationships to hold true)

Initial

Level

Final

Lab 5: Fluid Dynamics Lab A

Level

H

L

z-axis

p_2

p_1

$\Delta Z \rightarrow \Delta P$

Figure 2: Capillary fluid height and resulting difference in pressure.

Average

Level

Average fluid velocity

Fluid flow rate

Cross-sectional area of capillary

Change in pressure (Figure 2)

Term	Meaning	Constant Given	Preferred Units
R_e	Reynold's number	<>	<>

Lab 5: Fluid Dynamics Lab A

Symbol	Description	Value	Units
ρ_f	Density of fluid	<>	kg/m^3
μ_f	*Viscosity of fluid*	<>	$kg/m\text{-}s$
g	Acceleration of gravity	9.81 m/s²	m/s^2
d_{cap}	Diameter of capillary tube	1/8"	m
V_{avg}	Average velocity of fluid	<>	m/s
Q	Flow rate	<>	m^3/s
A_{cap}	Cross-sectional area of capillary	<>	m^2
r_{cap}	Radius of capillary tube	1/16"	m
ΔP	Change in pressure	<>	$kg/m\text{-}s^2$
ΔZ	Average level of fluid (includes capillary length)	.155 m	m

Lab Procedure:

Each of the teams is to complete 3 trials of each fluid for each task. Teams are to share data so that there will be many trials for each fluid for each super group.

Fluid Flow Rate Through a Capillary

1. The three distinct stations have plungerless syringes and fluid containers that are marked as canola oil, SAE 30 motor oil, and castor oil accordingly. Select one of these with which you have not yet experimented.
2. Clamp the end of the transparent Tygon tube.

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Lab 5: Fluid Dynamics Lab A

3. Remove the transparent Tygon tube end from the hole in the bottle cap.

4. Pick up the bottle and hold it so that the small nozzle is in the syringe opening and, with your thumb over the hole in the bottle cap, carefully squeeze an adequate amount (at least 20 mL so that the syringe is full, but not at risk of spilling!).

5. Replace the bottle below the transparent Tygon tubing.

6. Once you have filled the syringe, be absolutely sure that the container is placed under the hanging end of the capillary tube and that the capillary tube is actually hanging through the hole in the bottle cap with its end inside the bottle so that the flowing fluid is recycled into the container and not spilled or wasted!

7. With one teammate holding the tube clamp and another watching closely and ready with the stopwatch, remove the clamp from the tube. The fluid should begin to immediately flow through the capillary and into the fluid container.

8. The vertical plungerless syringe is graduated. When the fluid reaches the 15 mL line, begin timing with the stopwatch.

9. When the fluid level reaches the 10 mL line, stop timing.

10. Record the time in the provided worksheet.

11. Go back to step 2 and repeat until you have 3 trials for this fluid. It is important to refill the syringe for each experiment and to time the flow only between the 15ml and 10ml markings. This avoids exit effects on the flow that interfere with the measurement.

12. Go back to step 1 and continue until you have experimented with all three fluids.

13. Be sure to exchange data with the other teams in the class so that you will have several trials for each fluid.

14. Clean up any and all spills immediately and inform your lab instructor or teaching assistant.

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Home > Education > Learn About Viscosity > Viscosity Glossary

Viscosity Glossary

3A
a US industrial standard for process equipment design; required certification for clean-in-place capability.

Absolute Viscosity
the viscosity value associated with a Newtonian material

ASTM
American Society of Testing and Materials. United States organization responsible for establishing test standards.

Autorange
feature on standard Brookfield digital Viscometers/Rheometers which provides maximum viscosity value that can be measured using a specific spindle at a designed rpm.

bob
spindle used with PVS Rheometer;
also referred to as "bob/stator" because it does not rotate on this instrument. The sample cup rotates instead, causing the shearing action.

°C
a scientific unit of measurement for temperature; expressed as "degrees Celsius" or "degrees Centigrade."

Centipoise
a unit of measurement in the cgs system for viscosity; abbreviated cP.

Comm Port
the communications channel on a PC/computer via which data is transmitted.

Concentric Cylinder
a cylinder within a cylinder. For viscosity measurement, a cylindrical spindle rotates within a cylindrical chamber. Also known as "Coaxial Cylinder" because both cylinders have the same center line.

Cone Spindle
an almost flat circular spindle which has a small angle relative to the cup or plate on which it rotates.

CP or C/P
Brookfield terminology for cone and plate geometry.

Cylindrical Spindle
a spindle shaped like a cylinder.

Disc Spindle
a spindle having a flat circular disc near the bottom of the rod. The shape of the disc spindle makes the calculation of Shear Rate an approximation or average across the surface of the disc.

DIN
Deutsche Industrie Normung, German organization responsible for establishing test standards; similar to ASTM in United States.

dyneocm
a unit of measurement for torque.

°F
a scientific unit of measurement for temperature; expressed as "degrees Fahrenheit."

Fluid Ounce
a scientific unit of measurement for volume; abbreviated as oz.

Footprint
the bench space or area required for an item of equipment.

Gallon
a scientific unit of measurement for volume; abbreviated as gal.

Why Measure Viscosity?
Why Brookfield?
Questions
Help Me Choose
Glossary

Gap
the distance between the spindle and the chamber or cup in which the spindle is rotating.

Gram
a scientific unit of measurement for weight; abbreviated as gm.

Guard Leg
the protective bracket for spindles supplied with standard Brookfield LV and RV Viscometers/Rheometers.

HA
Brookfield torque range appropriate for measuring medium to high viscosity materials.
100% torque = 14,374 dyneocm.

HB
Brookfield torque range appropriate for measuring high viscosity materials.
100% torque = 57,496 dyneocm.

5xHB
Brookfield torque range appropriate for measuring "very" high viscosity materials.
Five times that of HB.
100% torque = 287,480 dyneocm.

Hz
unit of measurement for frequency; expressed as "Hertz" or "cycles per second."

In-line
process viscometer placement in a pipe.

KREBS Unit
a unit of viscosity measurement obtained when using a KREBS spindle rotating at 200 RPM; commonly used in the paint and coatings industry.

LCD
liquid crystal display

LED
light emitting diode display

Liter
a scientific unit of measurement for volume; abbreviated as L.

LV
Brookfield torque range appropriate for measuring low viscosity materials.
100% torque = 673.7 dyneocm.

mA
a scientific unit of measurement for current flow; expressed as "milliamp."

milli Liter
a scientific unit of measurement for volume; abbreviated as mL.

micro Liter
a scientific unit of measurement for volume; abbreviated as mL.

milli-Pascal seconds
a unit of measurement for viscosity; abbreviated as mPaos.

NIST
National Institute of Standards and Technology. US Government organization responsible for test standards.

Newtonian
a material whose viscosity value is the same at all shear rates.

Non-Newtonian
a material whose viscosity changes as shear rate changes.

On-line
use of a process viscometer to provide continuous viscosity measurement of a material during processing.

PC
personal computer.

pH

positive hydrogen ion index. Characterizes degree of acidity or alkalinity in a material.

Pint
a unit of measurement for volume; abbreviated as pt.

Plate Spindle
a flat circular spindle used to measure visco-elastic materials or materials containing particulate matter.

Pneumatic
air operated

Poise
a unit of measurement for viscosity; abbreviated as P.

PP
Brookfield terminology for plate and plate geometry.

Relative Viscosity
the viscosity value of a non-Newtonian material at a defined shear rate.

Rheology
the science which studies the deformation and flow of materials.

Rheometer
an instrument that measures the flow behavior of materials.

RPM
rotations per minute; a unit of measurement for spindle speed.

RS-232
data transfer protocol in the computer industry.

RTD
resistance thermal detector; type of sensor for measuring temperature

RV
Brookfield torque range appropriate for measuring medium viscosity materials.
100% torque = 7,187 dyneocm.

sec^{-1}
the scientific unit of measurement for shear rate; expressed as "reciprocal seconds" or "inverse seconds."

Shear Rate
the velocity gradient in a flowing material; the shape and rotational speed of the spindle rotating in a chamber or cup are used to calculate shear rate.

Shear Stress
the force per unit area used to move a material.

Spindle Geometry
the shape of a spindle. Brookfield spindles supplied with standard Viscometers/Rheometers (Dial Reading, DV-E, DV-I+, DV-II+Pro, DV-III+) are disc type. Other choices include Cylindrical, Cone, Plate, KREBS, etc.

Time to stop
Brookfield test procedure in DV-I+ and DV-II+ Viscometers which measures the viscosity of a material after a specified time interval.

Time to torque
Brookfield test procedure in DV-I+ and DV-II+ Viscometers which measures the time interval required to reach a specified torque value.

Torque Range
the torque measurement capability of a Brookfield Viscometer/Rheometer measured in dyneocm; designations such as LV, RV, HA or HB are used to define the Torque Range for a specific instrument.

Torque %
the amount of torque resistance measured by a rotating spindle immersed in a material.

Volt
unit of measurement for voltage unless otherwise indicated; abbreviated as V.

Viscometer

an instrument that measures the viscosity of materials.

Viscosity
the resistance of a material to flow.
Viscosity = shear stress/shear rate

Viscosity Range
the operating range of a Brookfield instrument using the spindle(s) identified.

Yield Stress
the amount of force required to cause a material to flow.

CONVERSION TABLES
Viscosity
   1 cP = 1 mPa·s
   1 P = 100 cP
   1 Pa·s = 1,000 mPa·s

Sample Volume
   1 L = 1000 mL
   1 mL = 1000 mL
   1 gal = 8 pt. = 3.7 L
   1 pt = 16 oz.

Torque Range
   LV = 673.7 dyneocm
   RV = 7,187 dyneocm
   HA = 14,374 dyneocm
   HB = 57,496 dyneocm
   5xHB = 287,480 dyneocm

Temperature
   °C = 5/9 (°F-32)

Please refer to Brookfield's publication
"More Solutions to Sticky Problems" for a detailed explanation of viscosity and Brookfield methodology for making measurements.

REFERENCE 5

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